Vehicle taxes as a climate policy instrument: econometric evidence from Spain

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Abstract

We study the local distortionary effects of notches in Spain's CO2-based vehicle registration tax on the distribution of new car CO2 performance. These effects are the smoking gun of carmaker strategic behaviour and affect in turn tax revenue and CO2 emissions. Using model-level data on all car registrations in Spain 2010-2020, we apply the bunching approach to the three thresholds of the tax scheme: 120, 160, and 200 gCO2/km. We find that the tax notches strongly affected market outcomes, resulting in the sale of about 388,000 more cars (overall) at or just below the thresholds compared to the respective counterfactuals without the thresholds. This translates into about €335 million of foregone tax revenue and only very limited extra abatement of CO2 emissions. Over 90-95% of all estimated bunching took place at the first threshold (120 gCO2/km). Over 60% of all estimated bunching took place before 2015. Bunching diminished over time, which reflects diminished effectiveness of the tax in both reducing CO2 emissions and generating revenue. Taking the interactions with both EU vehicle emission standards and similar CO2-related policies in other Member States into consideration is important for interpreting these results.

Keywords

CO2-based vehicle taxes, Notches, Bunching, Carmakers, Strategic behaviour, Emissions, Tax revenue, Policy interactions

1. Introduction

As a global leader in the fight against climate change, the European Union (EU) is committed to achieving net-zero greenhouse gas (GHG) emissions by 2050. Meeting this objective, enshrined in the European Climate Law (EP, 2021), requires drastic emission reductions in many sectors, including and especially road transport. In the EU, as in any modern economy, road transport is historically a major contributor to carbon dioxide (CO2) emissions. Moreover, CO2 emissions in this sector have proven particularly hard to reduce – a fact that can be explained by high abatement costs, behavioural and infrastructural barriers, as well as adverse market trends such as the rise of sport utility vehicles (SUVs). As a result, road transport alone currently makes up over 20% of the EU's CO2 emissions (EEA, 2024).

A complete and timely decarbonisation of road transport may only be achieved if the whole vehicle fleet is progressively turned into a stock of zero-emission vehicles (Hart et al., 2024). Accordingly, existing EU emission standards impose a time trajectory on the average CO2 performance of new vehicles consistent with the 2050 climate neutrality objective. Notably, 2035 has been set as the deadline by which all new vehicles sold in the EU must be zero-emission. EU Member States (MSs) also use a range of policy instruments, including CO2-based vehicle taxes and subsidies, which interact with the EU emission standards. The resulting patchwork of policy mixes offers opportunities for carmakers to behave strategically by gaming potentially imperfect national policies and by arbitraging between national markets. More generally, it contributes to the determination of heterogeneous economic and environmental outcomes within the EU.

In this paper, we focus on Spain's CO2-based vehicle registration tax as an instrument for decarbonising the national fleet: an instrument whose use is well-justified and desirable, but which also represents a case in point of inefficient design and increasingly less effective implementation. The design issue with the Spanish tax scheme is the discontinuities in the tax schedule, which determine notches in carmaker choice sets and in turn highly heterogenous incentives to improve the CO2 performance of vehicles placed on the market (Slemrod, 2013). The scheme is such that a different tax rate, namely 0%, 4.75%, 9.75%, or 14.75%, applies to a vehicle's list price depending on the CO2 bracket the vehicle falls in: 0-120, 121-160, 161-200, or >200 grams of CO2 per kilometre (gCO2/km), respectively. It follows that minor differences in vehicle CO2 performance can correspond to major differences in tax treatment depending on whether they straddle any two of the above brackets. Excessive incentives will be seized by carmakers for whom it is profitable to improve the CO2 performance of marketed vehicles just enough to qualify for more favourable tax treatment – all at the expense of fiscal revenues and with limited benefit in terms of emission reductions (Sallee and Slemrod, 2012; Sallee, 2011).[1]

As regards the implementation of the Spanish tax, the fact that the four CO2 brackets or the corresponding tax rates have never been updated – never since 2008 – brings to the fore a question of diminishing environmental effectiveness. Given increasingly stringent EU emission standards and exogeneous improvements in the CO2 performance of new vehicles over the past two decades, the tax scheme has likely become increasingly less effective in improving vehicle CO2 performance and also in raising tax revenue (Liu et al., 2014; Sallee, 2011). On the other hand, once shifts in vehicle sales across MSs in response to the EU standards are considered, vehicle taxes and subsidies in a MS may remain effective depending on how stringent they are relative to analogous policies in other MSs. The requirement for carmakers to reach their own EU-wide average vehicle CO2 target entails that differences between national CO2-based taxes and subsidies may result in some reallocation of more (/less) polluting vehicles towards MSs with more (/less) lenient legislation – a phenomenon known as internal carbon leakage. Furthermore, in a scenario of perfectly binding EU standards, the same policies may still be effective locally, but they would not be effective at the EU level (Linn and McConnell, 2019; Goulder et al., 2012; Goulder and Stavins, 2011).

Using microdata on newly registered cars over the period 2010-2019, we study the implications of the design and implementation of Spain's vehicle registration tax for economic efficiency as well as for effectiveness in emissions abatement and tax revenue generation. Our empirical investigation offers results

[1] Following the Volkswagen emissions scandal, Tanaka (2020) shows econometrically that very high incentives related to CO2-based vehicle taxation in Japan often resulted in fraudulent measurement of new car emission performances. In this paper, we take the official data on car CO2 performances at face value. Thus, we are agnostic as to whether carmaker strategic behaviour is perfectly legitimate or illicit.

that fall into two categories. First, we provide novel suggestive evidence consistent with the expectation of diminished effectiveness both over time and relative to other MSs that have made more coherent use of CO2-based vehicle taxes, e.g., the Netherlands and France. Second, we identify novel causal econometric evidence of strategic carmaker behaviour and related emissions abatement and foregone tax revenue. Applying bunching estimation methods (Kleven, 2016), we find the Spanish tax scheme caused the sale of about 388,000 cars that strategically qualified for more favourable tax treatment over the eleven-year study period. These 'bunching cars' met or slightly exceeded one of the critical CO2 thresholds for tax treatment and – crucially – only did so because the threshold existed. The vast majority of bunching cars (>90-95%) turned out to be concentrated at or just below the first threshold, which is 120 gCO2/km. Furthermore, we calculate that the bunching cars alone resulted in about €335 million of foregone tax revenue and only very limited abatement of CO2 emissions as expected.

Finally, a distinguishing feature of our analysis is the estimation of bunching effects year-by-year. There is value in this temporal detail as the bunching effects of the tax scheme depend on how the distribution of the CO2 performance of new vehicles sold changed from one year to the next. We find that the volumes of bunching cars and foregone revenue diminished over the years, with the former falling from over 85,000 in 2010 to less than 8,000 in 2020. Given the shifts of the distribution of new car CO2 performance over the study period, estimated diminishing bunching effects reflect diminished effectiveness of the tax in both reducing emissions and raising revenue.

The rest of the paper is structured as follows. Section 2 describes the workings of both the EU standards for new vehicle CO2 emissions and national CO2-based vehicle taxes and subsidies. Section 3 analyses the efficiency and effectiveness implications of the design and implementation of CO2-based vehicle taxes. Section 4 estimates the volumes of bunching cars, abated emissions, and foregone tax revenue caused by the notches in Spain's vehicle registration tax. Section 5 discusses the findings and concludes.

2. How Europe's vehicle fleet is being decarbonised

Many different policy instruments can be used to reduce CO2 emissions and other negative externalities of road transport (Noussan et al., 2020, Parry et al., 2007). In theory, fuel taxes and carbon prices stand out as potentially the most economically efficient instruments in reducing motor fuels consumption and related CO2 emissions. In practice, however, a variety of factors, including political economy limits to the use of Pigouvian pricing, consumer myopia in vehicle purchase decisions, and a growing pressure on governments to deliver significant emission reductions, mean that often in the real world second-best regulatory and fiscal interventions targeting new vehicles are key complements to fuel taxes or carbon prices when present (Anderson and Sallee, 2016).

In the EU, the policy mix for decarbonising road transport has long hinged on EU standards for fleet-average CO2 efficiency of new vehicles and a range of pricing instruments controlled by national governments, notably CO2-based vehicle taxes and subsidies, fuel taxes and – in a few MSs – carbon taxes.[2] In this section, we describe the two main policy instruments that have been used in tandem for greening the European vehicle fleet: (a) EU standards for CO2 emissions, and (b) national CO2-based vehicle taxes and subsides, also known as 'feebates' when jointly considered (Greene et al., 2005).

While CO2 emission standards and CO2-based feebates serve the same end goal, i.e., greening the vehicle fleet by inducing adoption and innovation of relevant technologies, the two types of instrument are not equivalent. First, standards directly influence carmaker production decisions, whereas feebates do so indirectly via vehicle prices and consumer decisions (Liu et al., 2011). Second, as standards only mandate minimum levels of fleet-average CO2 performance, they provide certainty about the minimum amount of future CO2 efficiency improvements, but are silent on the associated costs.[3] Conversely, feebates assign precise monetary values to any given difference in CO2 performance, but the amount of efficiency

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[2] Starting 2027, a new EU-wide cap-and-trade system (ETS2), operating in parallel to the existing EU Emissions Trading System (EU ETS), will add to the policy mix. By imposing a cap on overall regulated emissions, the ETS2 will in principle ensure that CO2 emissions from road transport as well as from buildings and small industry progressively fall to net zero by mid-century.

[3] Estimation of the costs of compliance with standards is not straightforward.

improvements that should then materialise is uncertain (German and Meszler, 2010). Third, by changing the relative prices of cleaner and dirtier vehicles, feebates induce efficiency improvements on top of those determined by standards. However, in scenarios with increasingly stringent standards, such that these become binding for an increasing share of carmakers, unrevised feebates produce increasingly smaller additional effects (Liu et al., 2014; Sallee, 2011[4]).

2.1 EU standards for CO2 emissions of new vehicles

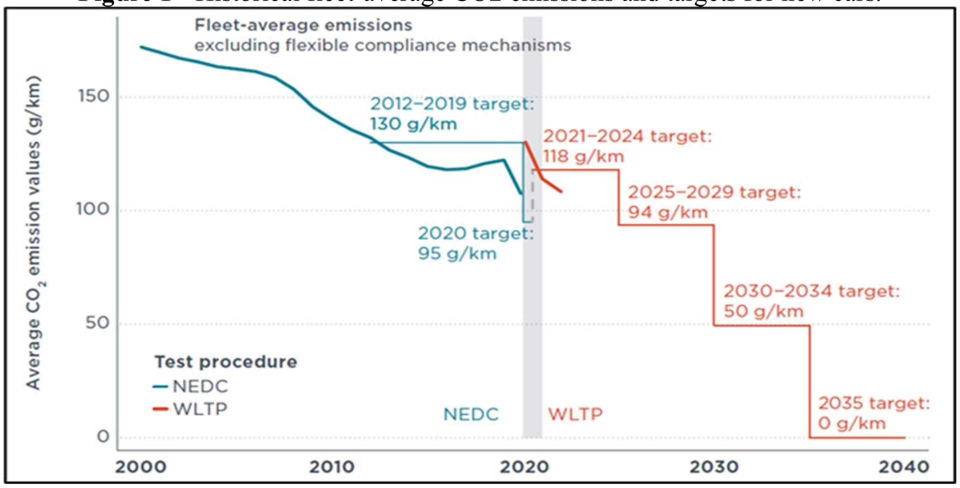
In the EU, standards for CO2 emissions of new vehicles play a key role in the sector's decarbonisation. After a first disappointing experience with voluntary standards, which did not deliver the targeted performance for new passenger cars (hereafter just 'cars'), namely an average of 140 gCO2/km to be reached by 2009, the EU adopted similar but mandatory standards for both cars (EP, 2009) and vans (EP, 2011) in 2009 and 2011, respectively. The standards for cars – cars are our focus in this paper – identified targets whereby on average all new cars registered in the EU, as well as Norway and Iceland, would have to emit at most 130 gCO2/km by 2015 and no more than 95 gCO2/km by 2020. Both targets were achieved by all regulated carmakers, though in 2020 only thanks to the use of flexible compliance mechanisms in some cases (see below).

In 2019, analogous but more ambitious targets were adopted for 2025 and 2030. Their levels were, respectively, 15% and 37.5% below that of the 2020 target (EP, 2019). Already in 2023, however, as part of the European Green Deal (EC, 2019), the same targets were revised to reflect greater environmental ambition. The 2030 target was adjusted to -55% (again relative to the 2020 target) and a definitive -100% target, to be reached by 2035, was set for the first time both for cars and vans (EP, 2023). Figure 1 shows the historical evolution of the average CO2 emission performance of all new cars registered in the EU, Norway and Iceland, over the period 2000-2022, against past and future targets. The CO2 metric represented in the graph, which does not take into account the flexible compliance mechanisms allowed by

[4] Sallee (2011), as most of the related US literature, considers fuel efficiency ('fuel economy') standards rather than CO2 efficiency standards. Still, the analysis is perfectly for EU emission standards too.

regulation, is based on the New European Driving Cycle (NEDC) up to 2020 and on the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) thereafter.[5] With stringent targets in place, the average emission efficiency of all new cars sold in Europe improved by 27% over 2019-2022. The main driver of this result was a surge in zero-emission vehicles, hence mainly battery electric cars, which in 2022 amounted to 13.4% of all new registered cars (Dornoff et al., 2024).

Figure 1 - Historical fleet-average CO2 emissions and targets for new cars.



Source: Dornoff et al. (2014).

Importantly, the EU CO2 emission standards, both for cars and vans, have always provided for flexibility mechanisms to reduce compliance costs.[6] Suffice it to mention the main ones. First, standards provide for differentiated targets for carmakers. Specifically, different targets apply to different carmakers depending on the average mass of the vehicles they produce. In this sense, heavier vehicles are allowed to emit more than lighter ones. Second, the use of so-called super credits is allowed to facilitate compliance with ambitious targets, but also to support the uptake of zero- and low-emission vehicles. In short, super

[5] Designed in the 1980s, the NEDC test has become outdated due to the evolution in technology and driving conditions. The WLTP is currently the main global standard for determining the levels of pollutants, CO2 emissions and fuel consumption of traditional and hybrid cars, as well as the range of fully electric vehicles.

[6] Regulatory compliance is also presided by penalties for missed targets. As it stands, if the average CO2 emissions of a carmaker's fleet does not meet the target in a given year, the carmaker must pay – for each of its new vehicles registered that year – an excess emissions premium of €95 per gCO2/km of target exceedance.

credits imply that vehicles with <50 gCO2/km (hence mostly battery- and plug-in hybrid electric vehicles) weigh more than other vehicles in the calculation of a carmaker's distance from its own target. Third, carmakers can act jointly to meet their targets by pooling together different brands (Turano and Van Ierland, 2024; Dornoff et al., 2024).

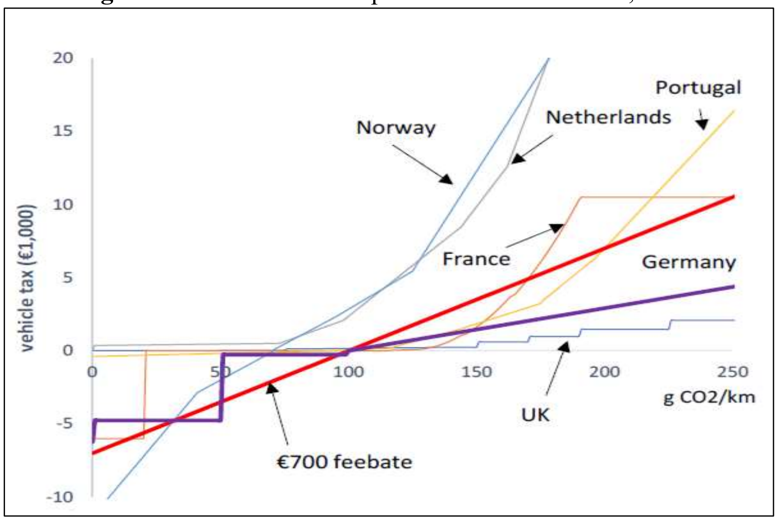
2.2 National CO2-based vehicle taxes and subsidies

Traditionally, European countries have made extensive use of taxation on vehicle purchase or ownership. Up until about twenty years ago, vehicle taxes were only indirectly related to CO2 emission performance, as they would typically depend on correlated vehicle characteristics such as weight, horsepower, or engine size. Beginning around 2006, however, many MSs shifted their tax systems to more directly target CO2 emissions (Klier and Linn, 2015). In particular, France and a growing number of other countries adopted CO2-based vehicle feebates whereby less CO2-efficient vehicles are taxed and more CO2-efficient vehicles are subsidised. The attractiveness of feebates can be explained with two of their generally expected properties: effectiveness, given changes in the relative prices of dirtier and cleaner vehicles, and revenue neutrality (or something close to it), since by design feebates are supposed to be fully or largely self-financed.

Over two decades, a wide variety of feebates have been used in the EU and Europe more generally. Feebate schemes can indeed differ across many dimensions, including notably: (a) the presence of explicit subsidies for lower-emission vehicles, in which case a feebate is 'full' or 'pure', as opposed to 'partial'; (b) their application to vehicle purchase or to vehicle ownership, respectively through one-off vehicle registration taxes or annual vehicle circulation taxes; (c) the shape of the tax-subsidy schedule, which may be a linear function of CO2 efficiency, or a piece-wise linear function, or a continuous non-linear function, or a step-wise function, etc.; (d) the levels of taxation and subsidisation applied to different CO2 efficiency levels; and (e) the pivot value of CO2 efficiency (or 'donut-hole' if an interval of values is considered), above which vehicles are taxed and below which vehicles are subsidised.

According to Ramji et al. (2024), 23 European countries currently have some form of CO_2-based taxation (both full and partial feebates being considered) on either vehicle purchase or ownership or both. To give an idea of the variety of feebate schemes that have been used in Europe, Figure 2 shows the derived tax schedules for the CO_2-based components of vehicle taxes in force in 2018 in six European countries (mostly registration taxes, except Germany which incentivises CO_2 efficiency primarily through annual circulation taxes).

Figure 2 – CO_2-based components of vehicle taxes, 2018.

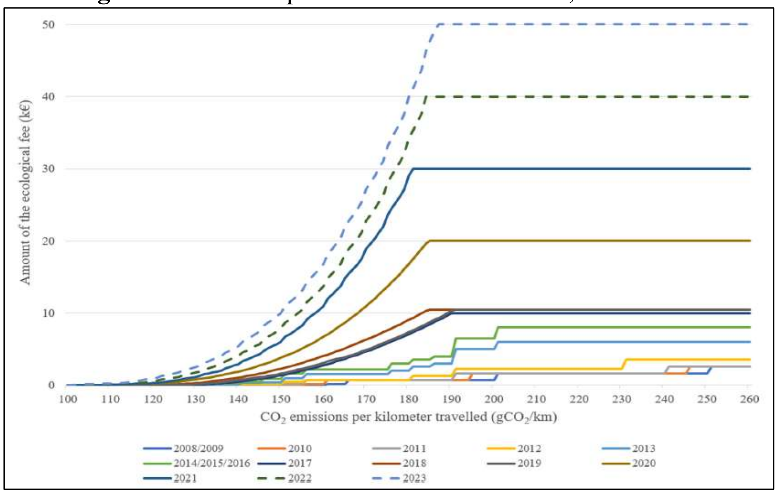


Note: (1) Circulation taxes for Germany are expressed on a lifetime basis assuming a 13 year life and 7% discount rate. (2) The red line represents a hypothetical linear feebate of €700 per gCO_2/km. **Source:** IMF (2021).

Both Norway and the Netherlands jump to the eye for their aggressive use of CO_2-based incentives (reaching €20,000 for vehicles with emissions ≥180 gCO_2/km), with the former also granting generous subsidies for low- and zero-emission vehicles (over €10,000 for zero-emission vehicles). On the opposite side of the spectrum, the UK made much lighter use of this type of incentive at the time.

A key aspect of the implementation of a CO_2-based vehicle feebate is the updating of its parameters for preserving or increasing the effectiveness of the scheme vis-à-vis any relevant technology or policy changes that may have materialised over time. In this sense, some countries are more attentive than others as they revise the parameters of their feebate schemes with a certain regularity. For example, both France and the Netherlands tend to adjust their feebate schemes on an annual basis. To illustrate, Figure 3 shows the evolution of the French vehicle registration tax (only the fee component is pictured here) over the period 2008-2023. The escalation of tax levels in the last few years is remarkable.

Figure 3 – Fee component of France's feebate, 2008-2023.



Note: The 2022 and 2023 schedules (dotted line) are those announced by the government. **Source:** Kessler et al. (2023).

By contrast, Spain's vehicle registration tax has never changed since its inception in 2008. Not only have the parameters of the Spanish tax never been revised, but also its very design is questionable on the grounds of economic efficiency – we will see why in the next section.

3. Design and implementation of CO2-based vehicle taxes: efficiency and effectiveness implications

In this section, we illustrate three critical aspects of CO2-based vehicle taxes in Europe. Focusing on Spain's vehicle registration tax, we analyse and provide suggestive evidence on the implications of (a) tax notches for economic efficiency, and (b) inert tax parameters (i.e., unrevised for many years) for effectiveness in reducing emissions and generating tax revenue. To follow, we analyse and again accompany with suggestive evidence the interactions between national taxes and EU emission standards.

3.1 Notched vs linear schedules

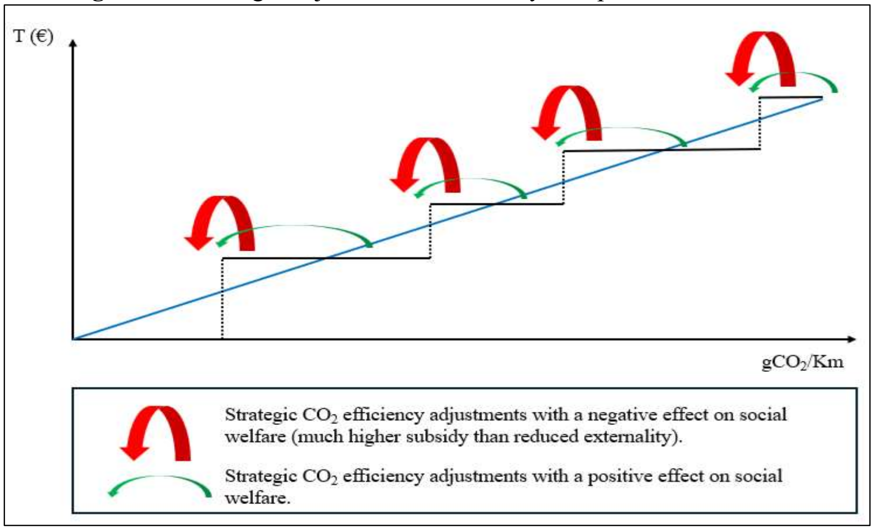
A tax schedule for the CO2 component of a vehicle tax can come in different forms. As we have seen, that of Spain's registration tax is a stepwise function, with four ad-valorem rates corresponding to four CO2 brackets (gCO2/km): 0% (0-120), 4.75% (121-160), 9.75% (161-200), and 14.75% (>200). In general, a stepwise tax schedule determines 'notches' and related incentives for firms or individuals to game the tax scheme, making it inefficient in social welfare terms. Notches are defined as "discontinuous jumps in the choice set of economic agents, arising when incremental changes in behaviour can cause discrete changes in net tax liability" (Slemrod, 2013). Taking this definition to the case of vehicle taxes, carmakers are the agents and their adjusting strategically the CO2 performance of the vehicles placed on the market is the behaviour that makes them benefit of more favourable tax treatment.

With reference to vehicle taxes, Sallee and Slemrod (2012) show why vehicle taxes with notches are economically inefficient. The logic goes as follows.[7] Under the assumption that the marginal social cost of carbon (MSCC) is constant over a vehicle's lifetime, a linear tax schedule, T = t × gCO2/Km, where t = MSCC, maximises social welfare given carmaker responses to both equal and optimal incentives for choosing the CO2 performance of vehicles. By contrast, a stepwise tax schedule determines incentives for strategic ('second-stage') improvements of CO2 performance which vary across vehicles. As the private cost of changing the CO2 performance of marketed vehicles increases with the size of adjustment, incentives for strategic adjustments of CO2 performance are higher (/lower) for vehicles falling closer to (/farther from) a preferential tax threshold. The implication for social welfare is that the sum of negative effects from inefficient adjustments, whereby foregone revenue exceeds the economic value of the avoided environmental externality, will be greater than the sum of positive effects from efficient adjustments, whereby the economic value of the avoided externality exceeds foregone revenue. This type of asymmetry

[7] Sallee and Slemrod's (2012) analysis refers to fuel economy rather than CO2 efficiency, but the same logic applies.

makes a notched tax schedule inefficient relative to a linear tax schedule with the same gradient (Figure 4).[8,9]

Figure 4 – Strategic adjustments induced by a stepwise tax schedule.



Note: The (blue) linear curve represents the first-best tax schedule alternative to the (black) second-best stepwise schedule. **Source:** Authors' elaboration based on Sallee and Slemrod (2012).

Focusing on the object of this paper, the supposed inefficiency of Spain's vehicle registration tax prompts a basic question: is there any evidence that carmakers have the ability to adjust the CO2 performance of marketed vehicles so as to game a notched tax if they wish? A wide literature shows that they usually do (see, e.g., Craglia and Cullen, 2019, Whitefoot et al., 2017, Klier and Linn, 2012, Knittel, 2012, Greene et al., 2005). A key qualification concerns the time required to modify the CO2 performance of vehicles sold. The very idea of 'gaming' a tax notch implies a relatively cheap and almost immediate response. Slemrod and Sallee (2012) provide a few examples of such interventions: substituting vehicle parts to reduce weight, engine recalibration, use of low-friction lubricants, modifications to tires, small

[8] The coarser a stepwise schedule (i.e., with broader intervals of gCO2/Km for which the same tax rate applies), the greater the efficiency gap with the corresponding alternative linear schedule.

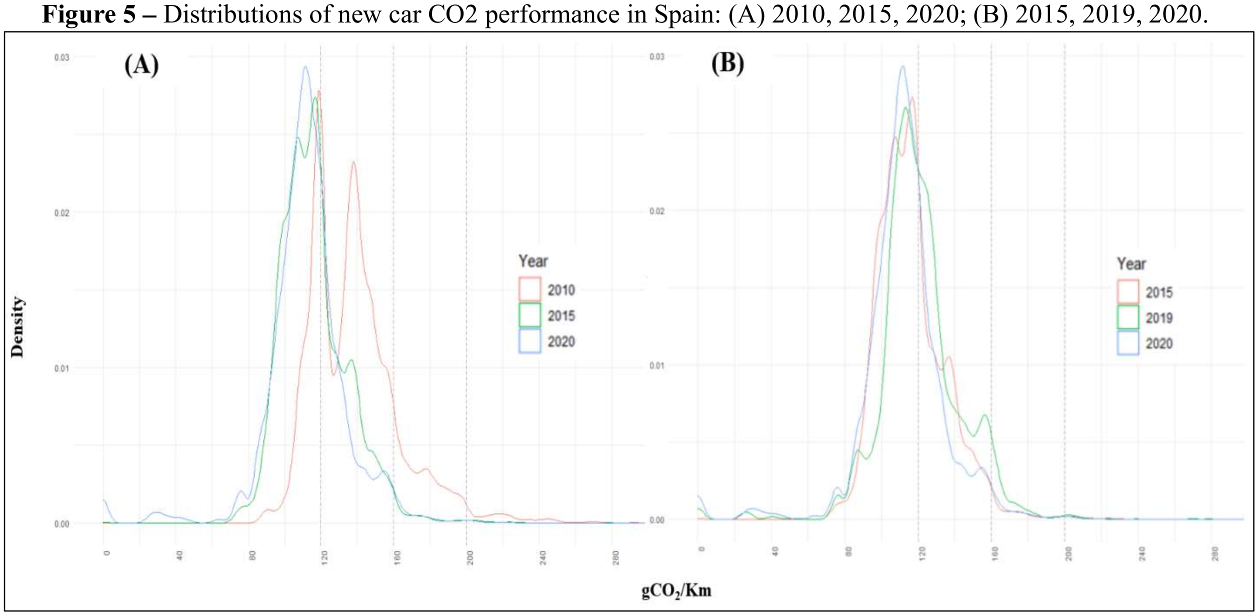
[9] Why, then, should a stepwise tax schedule ever be chosen by a government? Usual arguments in favour of stepwise schedules over alternative designs include: (a) salience, meaning a greater ability to get people's attention about the tax base and, therefore, to influence their behaviour; and (b) ease of implementation, which implies lower administrative costs. Whether these benefits outweigh the cost of strategic responses induced by notches is an empirical question. The literature, however, seems to consistently lean towards a negative answer (Sallee and Slemrod, 2012).

aerodynamic changes. Alternatively, the same goal could be achieved by strategically lowering the prices of vehicles that already meet a critical CO2 threshold. We do observe, also in our data, ranges of CO2 performance that suggest carmakers often have the possibility to sell cars of the same model below or above a CO2 threshold depending on technical features specific to a model variant such, as weight and horsepower.

3.2 Inertia vs updating

Whenever CO2-based vehicle taxes (or feebates more generally) are used in tandem with vehicle CO2 emission standards, revising the tax schemes on a regular basis is good practice. Failing that, in the face of increasingly stringent standards or exogeneous improvements in the CO2 performance of new vehicles, inert CO2-based taxes are destined to lose effectiveness (Liu et al., 2014; Sallee, 2011). As far as environmental effectiveness is concerned, standards rather than taxes would increasingly do the heavy lifting of decarbonisation. This appears to be the case of Spain's CO2-based vehicle registration tax, given the inertia of its parameters – never adjusted in many years – and ever more stringent EU emission standards.

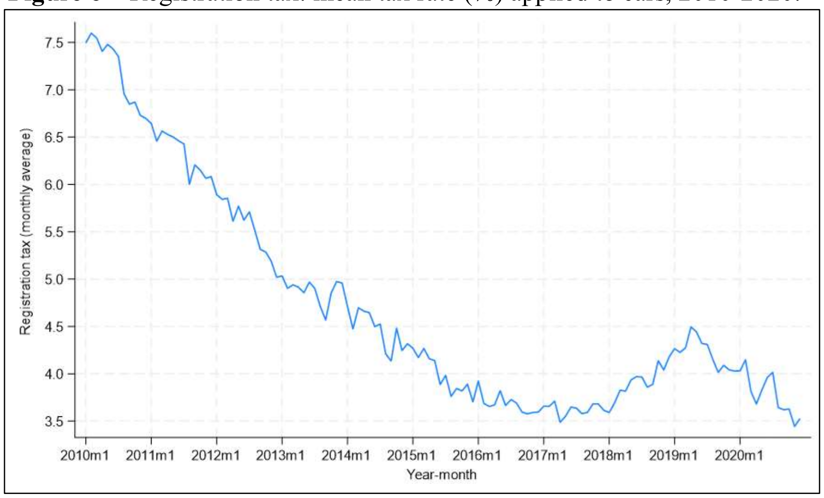
Figure 5 – Distributions of new car CO2 performance in Spain: (A) 2010, 2015, 2020; (B) 2015, 2019, 2020.



Source: Authors' elaboration.

Do our data offer any evidence in support of this conjecture? Figure 5(A) shows the distributions of CO2 performance for all new cars registered in Spain in 2010 (orange), 2015 (green), and 2020 (blue). The three CO2 thresholds of the Spanish registration tax, namely 120, 160, and 200 gCO2/km, are demarcated by vertical dotted lines. The distribution of CO2 performance shifted over time: strongly to the left, between 2010 and 2015, and then again slightly to the left, between 2015 and 2020. Simple inspection of these data does not allow us to identify the underlying driving forces. However, a key role of EU emission standards becomes particularly plausible when the distribution of CO2 performance for cars registered in 2019 is compared with that for cars registered in 2015. As Figure 5(B) shows, the 2019 curve lies on the right (not on the left) of the 2015 curve. The same shifts of the distribution of CO2 performance are reflected in the evolution of the mean tax rate applied to new cars sold (Figure 6).

Figure 6 – Registration tax: mean tax rate (%) applied to cars, 2010-2020.



Source: Authors' elaboration.

The way EU emission standards work provides an explanation for the temporary post-2015 recoil of average CO2 performance. Both 2015 and 2020 were target years for the standards, meaning the year for carmakers to comply with their targets. The years in between, 2016-2019, were not target years. According to Dornoff et al. (2024), after the 2015 targets were met, and in the absence of enforced targets before 2020, average emissions of new cars in Europe increased by 0.7 gCO2/km per year. Taken together these facts suggest that, both in Spain and at the EU level, the EU emission standards tended to be binding over 2010-2015, but not over 2016-2019. Consequently, not only do the standards appear to have been a determinant of fleet-average CO2 performance, but they would also have influenced the effectiveness of inert CO2-based vehicle taxes, like Spain's, over time.

3.3 Interactions with EU emission standards

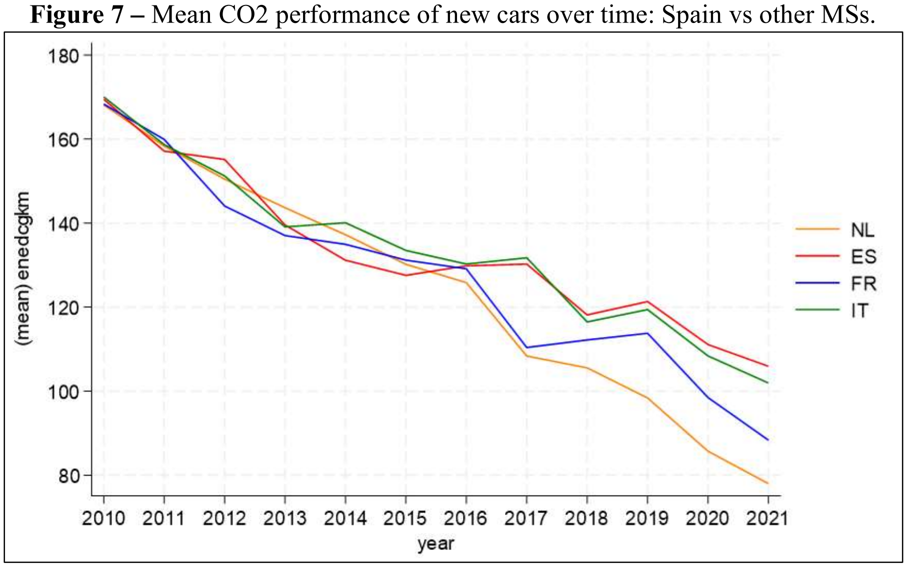
Potential overlaps between EU and MS policy instruments in the climate and energy domain are a well-known issue. Much has been learnt about their interactions, especially when it comes to national instruments and the EU ETS. However, the interactions between MS policies and EU emission standards for greening new vehicles have so far received very little attention. In the literature, problems related to 'nested' policies in this area have been highlighted mainly with reference to the US context, where overlapping federal and state policy instruments exist (Linn and McConnell, 2019; Goulder et al., 2012; Goulder and Stavins, 2011). Still, bearing in mind the differences between the two continents, some key indications from this literature are equally relevant for the European context.

EU emission standards set a series of targets to be reached by given years for the average CO2 performance of all new vehicles registered in the EU. Each of these targets is broken down into targets for carmakers, or pools of carmakers, which must be met at the EU level. How vehicle sales are distributed within the EU is, therefore, not relevant for compliance. Assuming that the standards are binding on carmakers, such a setting has a few important environmental and economic implications. From an EU perspective, one implication is internal carbon leakage, whereby national policies overlapping with the standards result in only partial net additional improvements in CO2 efficiency of new vehicles at the EU level. The reason is carmakers would sell more low-emission vehicles in European countries with more stringent overlapping policies in place, but, on the other hand, they would sell more high-emission vehicles in other European countries with less stringent ones (if any) in place. Also from an EU perspective, differences in stringency between national policies overlapping with the EU standards imply higher-than-optimal abatement costs.

From the perspective of a MS, such as Spain, national policies overlapping with EU emission standards are still effective in influencing environmental and market outcomes domestically. More interestingly, however, the mechanisms described imply that similar overlapping policies in other MSs may also determine domestic outcomes. For example, if France or the Netherlands decided to levy higher taxes on high-emission vehicles, that would create an incentive for carmakers to increase sales of high-emission vehicles in other MSs, where taxation is more favourable. In this sense, therefore, the combination of binding EU emission standards and heterogeneous overlapping national polices can be expected to exacerbate environmental differences between MSs.

So, again, do our data show trends that are at least consistent with this hypothesis? Figure 7 contrasts the mean CO2 performance of new cars registered in Spain and in other three MSs, over the period 2010-2021.

Figure 7 – Mean CO2 performance of new cars over time: Spain vs other MSs.



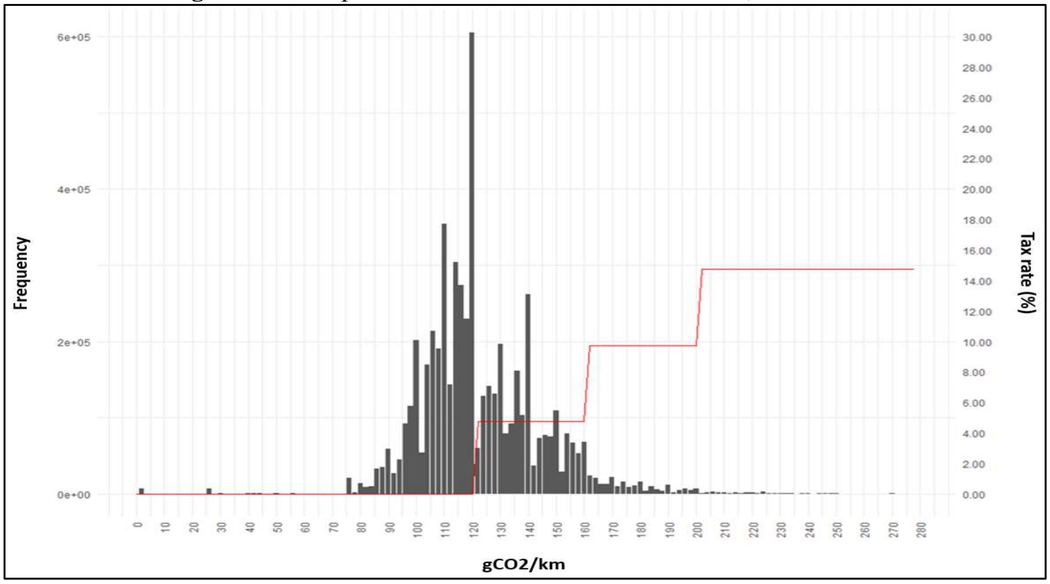
Source: Authors' elaboration.

Since the early 2010s, the Netherlands and France, more so than Spain, have leveraged vehicle taxes and subsidies for greening the national fleet. This is reflected both in the tax rates that the Dutch and French governments have applied and in the periodic revision of those rates. Italy, by contrast, is taken here as a case of inertia regarding CO2-based vehicle taxes, in a way that is similar to Spain (Ramji et al., 2024). The graph shows patterns suggesting that these differences combined with the EU emission standards may have determined growing environmental differences between MSs. Notably, the operation of ever tighter EU emission standards, enforced at five-year intervals starting 2015, coincides with a decade in which the average CO2 performances of cars registered in the Netherlands and France clearly diverged for the better from those of cars registered in Spain and Italy.

4. Spain's vehicle registration tax: bunching cars, foregone revenue, emission reductions

We can now evaluate Spain's vehicle registration tax by estimating the effects of its notched design on carmaker behaviour and on a few key consequent outcomes. The starting point is the hypothesis that notches have distorted the CO2 performance of new vehicles sold. Figure 8, which represents the distribution of new car CO2 performance over the period 2010-2020, does show that cars bunch in correspondence of the three critical CO2 thresholds, namely at or just below 120, 160, and 200 gCO2/km. Our first objective is thus to estimate the magnitude of such distortions. We will estimate the number of (excess) bunching cars, meaning those cars whose CO2 performance met or slightly exceeded one of the thresholds and, crucially, only did so because the threshold was there.

Figure 8 - CO2 performance of new cars and tax rates, 2010-2020.



Source: Authors' elaboration.

Bunching cars as just defined are the smoking gun of carmakers who were able to game the tax scheme; that is, to adjust in some way the CO2 performance of cars sold and profit from more favourable tax treatment. Estimation of bunching cars naturally leads to the question of how much tax revenue was lost as a result. Answering this question with an approximate calculation will be straightforward as our dataset includes information on car prices.

The Spanish tax was established with the dual aim of raising revenue and reducing externalities associated with CO2 emissions. In general, the flipside of less revenue raised by carbon pricing instruments is more abated CO2 emissions. However, because the Spanish tax is actually a CO2-based tax on car value (not a tax on gCO2/km) and because carmaker strategic behaviour only involves (very) limited improvements in the CO2 performance of vehicles sold, volumes of abated emissions are expected to be proportionately much smaller than volumes of foregone revenue. To provide a quantitative indication of the big disparity between changes in revenues and emissions caused by notches, hence their extraordinarily high implicit abatement costs, we will resort to back-of-the-envelope calculations.

Finally, given the shifts in the distribution of new car CO2 performance over the years, the results just described will be detailed on an annual basis.

4.1 Data

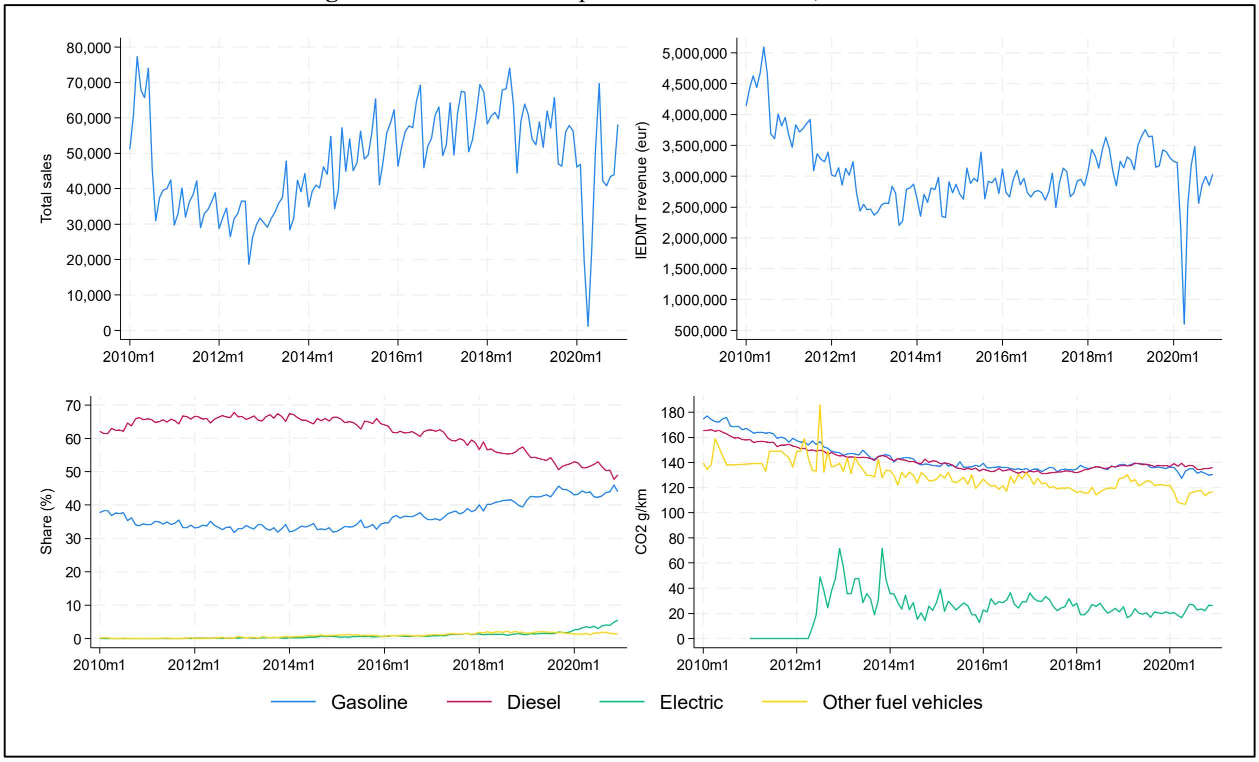
The data used for our econometric analysis are sourced from JATO Dynamics, a market research company. We observe model-level information on car prices and taxes, CO2 performance, and other major car attributes covering all new cars sold in Spain to private individual buyers between 2010 and 2020, on a monthly basis. We do not observe cars purchased by large buyers such as car rental companies, corporations, or public authorities. Table 1 shows summary statistics of our data.

Table 1 - Summary statistics, sample period 2010-2020.

Variable	Obs	Mean	Std. dev.	Min	Max
Sales per model	289,902	21.7	57.4	1	1,994
Retail Price	282,018	32,933.8	20,441.8	7,200	859,669
Retail Price before taxes (€)	276,339	26,075.2	15,396.9	5,726	710,470
Registration tax rate	276,339	4.65	4.40	0	14.75
Registration tax (€)	276,339	1,471.0	2,340.4	0	63,573.5
Gasoline (=1)	289,902	0.37	0.48	0	1
Diesel (=1)	289,902	0.61	0.49	0	1
Electric (=1)	289,902	0.01	0.10	0	1
Other fuel (=1)	289,902	0.01	0.10	0	1
CO_2 (g/km)	276,339	141.32	38.54	0	512
Horsepower	288,310	146.41	65.44	18	1,100

Figure 9 shows the evolution of new car sales in Spain's market along with other relevant trends. After 2010, the great financial crisis drastically reduced car sales, which then slowly recovered to their pre-crisis levels (top left panel). The revenue generated by the registration tax largely followed the evolution of sales, but was also affected by compositional changes in the vehicle fleet and related changes in CO2 emissions. More specifically, Spain has been slowly transitioning from diesel to gasoline car. While in 2010 diesel cars accounted for over 60% of the new car fleet, by 2020 they had gone down in number to about 50%, almost entirely replaced by gasoline cars. Only in the last months of 2020 did electric vehicles reach 5% (bottom left panel). In terms of CO2 performance (gCO2/km), cars with internal combustion engines exhibit similar downward trends (bottom right panel). The combination of these market and technology developments has gradually improved the average CO2 performance of the national fleet.

Figure 9 – Evolution of Spain's new car market, 2010-2020.



Source: Authors' elaboration.

4.2 Methodology

We implement the bunching approach (Saez, 2010, Chetty et al., 2011; Kleven and Waseem, 2013; Kleven, 2016) to estimate the distortionary effects of notches in the Spanish vehicle registration tax on the distribution of new car CO2 performance.

4.2.1 General approach

To estimate the number of cars bunching at or just below any of the three CO2 thresholds, we need to estimate the (local) counterfactual (CF) distribution of new car CO2 performance; that is, the distribution that would have materialised in the neighbourhood of the threshold had the threshold not been there. The standard approach for estimating the CF distribution is to fit a flexible polynomial to the observed distribution, excluding data in a range around the threshold z∗, and then extrapolate the fitted distribution to the threshold (Figure 10). In formal terms, grouping cars into gCO2/km-bins, the following regression model is fitted to the observed distribution (Kleven, 2016; Kleven and Waseem, 2013):

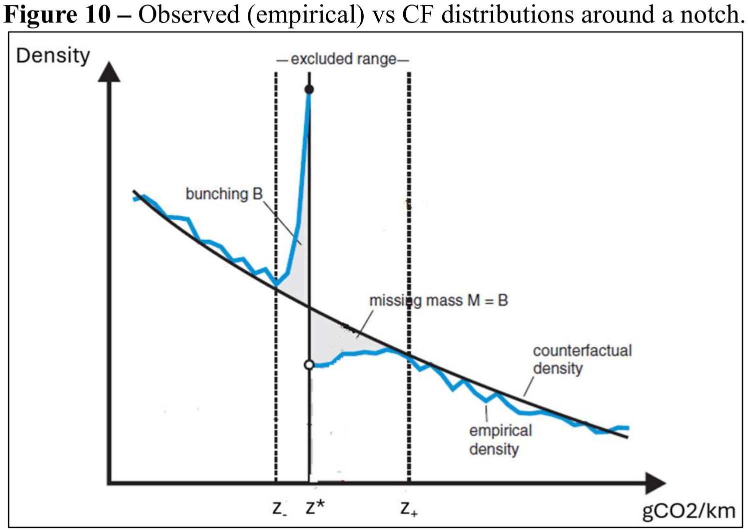
$$c_j = \sum_{i=0}^{p} \beta_i \cdot (z_j)^i + \sum_{i=z_-}^{z_+} \gamma_i \cdot \mathbf{1}\left[z_j = i\right] + v_j$$

[1]

where c_j is the number of cars in bin j, z_j is the CO2 performance level in bin j, [z_-, z_+] is the excluded range, p is the order of the polynomial, and v_j is the error term.

The CF distribution is then estimated as the predicted values from [1] omitting the contribution of the dummies in the excluded range, [z_-, z_+]. That is, the estimated CF distribution is given by $\hat{c}_j = \sum_{i=0}^{p} \hat{\beta}_i \cdot (z_j)^i$. Polynomials of different degrees (p) are fitted and the one producing the smallest Bayesian Information Criterion (BIC) value is selected.

Figure 10 – Observed (empirical) vs CF distributions around a notch.



Source: Kleven and Waseem (2013).

Once the CF distribution is estimated, the bunching mass (BM) is estimated as the difference between the observed and CF bin counts in the low-tax side of the excluded range. That is,

$$\widehat{BM} = \sum_{j=z_-}^{z*} \left(c_j - \hat{c}_j\right)$$

[2]

In our application, the BM represents the number of cars sold whose CO2 performance levels are the result of strategic behavior by carmakers to obtain more favorable tax treatment. A threshold by itself is the cause of carmaker strategic behaviour. If a threshold did not exist, a BM would not exist either.

4.2.2 The data windows for estimation

The described approach relies on a credible determination of the excluded range, $[z_-, z_+]$. The excluded range should span the entire bunching window, meaning the whole area affected by bunching responses. As such, the bunching window underlies both the BM, on one side of the threshold (threshold included), and an equivalent missing mass (MM), on the other side (Figure 10). With notches (as opposed to kinks), the excluded range is typically an asymmetric interval around the threshold. To identify the excluded range, we follow Kleven and Waseem (2013). Specifically, the lower bound of the excluded range (z_-) is determined through inspection of the empirical distribution. By contrast, the upper bound (z^+) is determined (given the lower bound) subject to the constraint that estimated BM and estimated MM are equal in volume, i.e., $\widehat{BM} = \widehat{MM}$.

A second type of data window plays an important role in bunching estimation, especially when multiple thresholds are present. This is our case, as we are dealing with three thresholds: 120, 160, and 200 gCO2/km. In general, the bunching approach can only detect the local causal effects of a threshold. Therefore, it does not require information on the global shape of the empirical distribution, but rather only on its local properties (Kleven, 2016). For any given threshold, only the data falling in a window around the threshold may be used to estimate the CF distribution locally. In our application, symmetric windows of 60 units around a threshold are always considered, meaning equally for each threshold 30 gCO2/km on one side and 30 gCO2/km on the other. Such window size allows us to collect sufficient data for estimating the CF distributions while minimising the risk of overlaps between ‘areas of influence’ of neighbouring thresholds.

4.3 Results

4.3.1 Pooled-data analysis

The first set of results refers to pooled data on all car registrations in Spain over the period 2010-2020. Upon inspection of the empirical distribution, we decided to focus for each and every threshold (z^*) on lower bounds of the excluded range (z_-) that are 2 or 1 gCO2/km below the threshold or even exactly at the threshold. Depending on the degree of the fitted polynomial function (p), different estimates of the BM were obtained and occasionally also different upper bounds (z_+) were determined. For each threshold and each alternative lower bound of the excluded range, Table 2 shows the most plausible results, i.e., those produced by the polynomial with the lowest BIC value.[10]

Table 2 – Excluded ranges and bunching masses produced by the best fitting polynomial functions.

Notch point z^* (gCO2/km)	Polynomial degree p	Excluded range $[z_-, z_+]$	Estimated BM $\widehat{BM}^a$	t-statistic^b
120	2	[118, 126]	**370,696** (88,977)	4.17
120	2	[119, 127]	**390,621** (69,898)	5.59
120	3	[120, 121]	**111,643** (65,431)	1.72
160	1	[158, 161]	19,395 (53,764)	0.36
160	2	[159, 162]	24,360 (51,665)	0.47
160	n.a.	[160, n.a.]	n.a.	n.a.
200	2	[198, 204]	3,559 (4,006)	0.89
200	1	[199, 201]	2,453 (3,289)	0.75
200	n.a.	[200, n.a.]	n.a.	n.a.

Note: (a) Bootstrap standard errors in parentheses. **(b)** In a t-test where H_0: MB=0, H_1: MB>0, and α=0.1, the null hypothesis is rejected if t >1.325.

[10] For each threshold and lower bound of the excluded range, polynomials of up to degree 5 were considered.

The results clearly indicate that major volumes of excess bunching cars are detected in correspondence of the first threshold, i.e., at or just below $z^* = 120$ gCO2/km. Focusing on the outcomes with the highest t-statistics, it is estimated that, over the period 2010-2020, carmakers managed to sell over 390,000 cars tax-exempt by means of strategic pricing or adjustment of car CO2 performance. In addition, it is estimated that almost 25,000 cars were sold and taxed at 4.75% (the tax rate applied between 121 and 160 gCO2/km) instead of 9.75%, as a result of carmaker strategic behaviour. However, the estimated BM is not significantly greater than zero for any of the usual confidence levels. The same qualification applies to the estimated BM at or just below the third threshold, $z^* = 200$ gCO2/km. In the upper tale of the distribution, however, the estimated volume of excess bunching cars is – unsurprisingly – substantially smaller ($\widehat{BM}$ = 3,559).

4.3.2 Year-by-year analysis

The results obtained from the pooled data can be refined and extended by applying the same econometric method to the data from each individual year. More specifically, there are at least two good reasons for replicating the analysis year by year. First, annual shifts in the distribution of new car CO2 performance – shifts that, as we saw, do not necessarily go always in the same direction – may act as a confounding factor in the analysis with pooled data. Second, annual variations in the car market, in terms of both number of cars sold and car prices, determine fluctuations in the volume of (foregone) tax revenue that could not be appreciated using pooled data.

We focus on the results referring to the first CO2 threshold ($z^* = 120$ gCO2/km), where the vast majority of bunching is found to take place. As Table 3 shows, the largest bunching mass materialised in 2010 ($\widehat{BM}$ = 85,850), the first year of the study period. The overall trend of the estimated BM is obviously downward, but not monotonic.

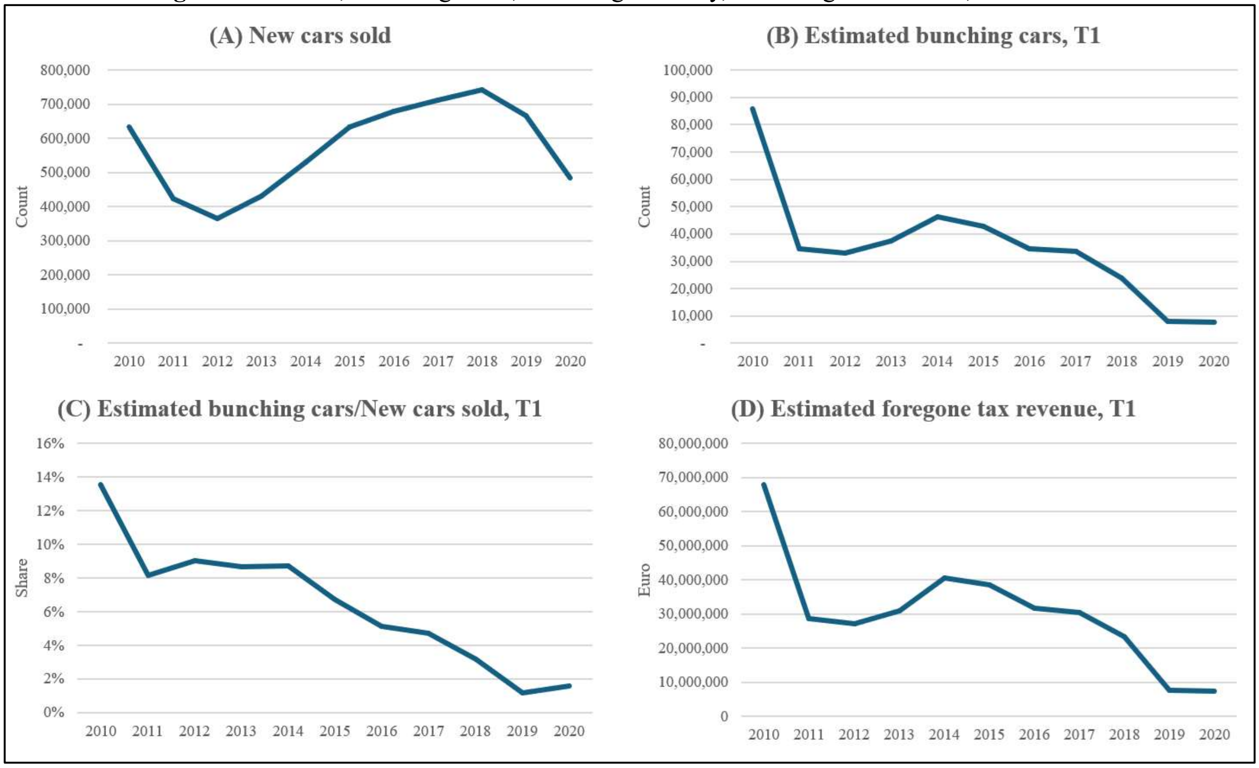
Table 3 – Estimated bunching at $z^* = 120$ gCO2/km, by year.

Year	Polynomial degree p	Excluded range $[z_-, z_+]$	Estimated BM $\widehat{BM}^a$	t-statistic[b]	$\widehat{BM}$ as a % of all new cars sold
2010	1	[119, 147]	**85,850** (5,267)	16.30	13.6%
2011	2	[119, 126]	**34,509** (7,559)	4.57	8.2%
2012	2	[119, 126]	**33,012** (5,347)	6.17	9.0%
2013	2	[119, 127]	**37,421** (9,265)	4.04	8.7%
2014	2	[119, 129]	**46,229** (12,531)	3.69	8.7%
2015	2	[119, 125]	**42,667** (11,656)	3.66	6.7%
2016	3	[119, 125]	**34,729** (10,513)	3.30	5.1%
2017	4	[119, 125]	**33,704** (8,936)	3.77	4.7%
2018	4	[119, 123]	**23,723** (6,752)	3.51	3.2%
2019	3	[119, 121]	**7,975** (5,612)	1.42	1.2%
2020	5	[119, 124]	**7,726** (3,549)	2.18	1.6%

Note: (a) Bootstrap standard errors in parentheses. **(b)** In a t-test where H_0: MB=0, H_1: MB>0, and $\alpha=0.1$, the null is rejected if $t > 1.325$.

After a sharp drop in 2011 ($\widehat{BM}$ = 34,509), a lower estimated BM is not observed until 2017 and, in fact, bunching turns out to be on the rise between 2012 and 2014 ($\widehat{BM}$ = 46,229). It is the case that up until 2014 estimated bunching volumes and total car sales always moved in the same direction one year to the next. This positive correlation vanishes starting 2015, which suggests one or more other factors – stronger than the scale effect of market size – had come into play. The documented shifts in the distribution of new car CO2 performance are the relevant context. 2015, in particular, coincides with the first target year of the EU emission standards. By expressing $\widehat{BM}$ as a share of all new cars sold the same year, we get an indicator of bunching 'intensity' whose evolution over time is not directly affected by the size of the car market. The downward trend of this indicator throughout the study period (Table X, last column, and Figure X, panel X) points to an issue of obsolescence of the tax threshold relative to the mobile distribution of new car CO2 performance. In other words, and in a more general sense, the trend of this indicator points to an issue of diminished effectiveness of the tax over time.

Figure 11 – Sales, bunching mass, bunching intensity, and foregone revenue, 2010-2020.



Finally, we estimated both the amounts of foregone tax revenue due to the tax notches and, using back-of-the-envelope calculations, the amounts of abated CO_2 emissions over the lifetime of bunching cars (Table 4). Again focusing on $z^* = 120$ gCO_2/km, the evolution of foregone revenue closely follows that of the number of bunching cars (from almost 68 million euro in 2010 to less than 7.5 million euro in 2020).

As regards abated emissions, our calculations rest on one main simplification. Namely, we approximate the average improvement in car CO_2 performance with the distance between the midpoint of $[z^*, z_+]$ and the midpoint of $[z_-, z^*]$. The estimated amounts of abated emissions turn out to be very small in absolute terms – as expected. More important, however, if the same abated emissions are compared to the corresponding volumes of foregone tax revenue, the resulting implicit average abatement costs of notches are extraordinarily high.

Table 4 – Estimated foregone tax revenue an abated CO2 emissions, at $z^* = 120$ gCO2/km, by year.

Year	Estimated BM (number of cars)	Avg. pre-tax car price (€)	Estimated foregone tax revenue (€)	Estimated avg. CO2 improvement (gCO2/km)	Estimated abated CO2 emissions (tCO2)
2010	85,850	16,622	67,782,051	14.5	13,927
2011	34,509	17,502	28,688,539	4.0	1,544
2012	33,012	17,384	27,258,948	4.0	1,477
2013	37,421	17,380	30,893,193	4.5	1,884
2014	46,229	18,481	40,581,779	5.5	2,845
2015	42,667	18,963	38,431,631	3.5	1,671
2016	34,729	19,175	31,631,377	3.5	1,360
2017	33,704	19,042	30,485,081	3.5	1,320
2018	23,723	20,777	23,412,214	2.5	664
2019	7,975	20,058	7,597,928	1.5	134
2020	7,726	20,108	7,379,670	3.0	259
Total	387,543	-	334,142,410	-	27,084

5. Discussion and conclusions

The econometric analysis has produced results with clear implications for future policy reforms. Firstly, notches in Spain's vehicle registration tax have caused strong bunching effects. In concrete terms, that means carmakers were often able to act strategically and sell cars that met (just about) a critical CO2 threshold for the sole purpose of getting more favourable tax treatment. In particular, the first threshold, set at 120 gCO2/km, is where most of the bunching occurred. The associated loss of tax revenue has been substantial in volume and accompanied by only very modest CO2 emission reductions. By inducing strategic tax avoidance, notches have made the Spanish tax a less effective instrument for raising revenue and a less efficient instrument for abating CO2 emissions. Thus, our first recommendation is to remove the notches and, ideally, replace them with a linear schedule. Offering no opportunities for strategic tax avoidance, a linear tax schedule would generate more revenue while reducing emissions at a lower cost. The current ad-valorem tax rates (percentages of vehicle prices) should also be replaced by a tax rate schedule expressed in euros per gCO2/km – our second recommendation. The more direct the taxation of a negative externality, the greater the economic efficiency. In our case, for the purpose of reducing CO2 emissions, taxing vehicle emissions per km would be more efficient than taxing vehicle market value.

A second result of the econometric analysis is that bunching effects have decreased in magnitude over the eleven-year study period. At the root of this trend is what we may call 'tax inertia within a dynamic context'. Specifically, while the parameters of the Spanish tax scheme were never revised, the average CO2 performance of new cars sold significantly improved. Increasingly stringent EU standards for CO2 emissions of new vehicles appear to have been a key driver – suggestive evidence was provided. In any case, the effectiveness of the tax alone in getting greener vehicles on the road has declined. The same applies for the effectiveness of the tax in generating revenue. Again, it is clear what the policymaker should do: the tax parameters should be regularly revised based on emission reduction and revenue generation objectives. At a minimum, even if the tax schedule was to remain a stepwise schedule or the tax rates were not to change, the CO2 brackets should be revised periodically.

Finally, we wish to stress a qualitative, preliminary result of our more general investigation. It would appear that the combination of EU emission standards and heterogeneous overlapping national policies has determined increasing differences between MSs in the average CO2 performance of new vehicles sold. This type of gap between Spain and other MSs that have made more coherent use of CO2-based vehicle taxes, such as the Netherlands and France, has clearly widened over the past decade. More rigorous analysis of these observed trends and their implications should be the object of future work.

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